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Simulation platform of a free-space optical network under multipath fading channel

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Simulation platform of a free-space optical network under multipath fading channel

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Abstract: This paper deals with channel modelling in free space optics (FSO) network using MATLAB 2017a. A detailed mathematical methodology to design an optical network is proposed under various small scales fading effects such as Rayleigh, and Rician fading which degrades the execution of a wireless channels. In the proposed work, the system is implemented at different sample rates, Various Doppler shifts through a flat fading channel. To modulate the data, Quadrature phase-shift keying (QPSK) modulation is used. The simulated effect of the fading channel of Rayleigh and Rician is contrasted in this paper.

Keywords: Small Scale fading channel, Wireless communication, Filtering sequence, QPSK, Probability distribution function.

1. Introduction

Ultra-capacity and high-speed optical networks have become a necessary part of any transmission network. Hence, the recent development of communication systems demands the support of mobility which is possible only using wireless channels. Due to high demands for the data rate, it is very important to avert the practical production of such technological infrastructure[1]. Hence, the Free space optics concept comes into the picture, which is an optical communication to transmit the signal through free space or air. The important benefits of this system are license-free spectrum allocation, immunity from radio frequency interference, large protection, high speed, fast installation, and last but not least backup support to fiber-optic communication[2][3]. Since the wireless channel is used, it is subjected to various effects such as reflection, refraction, or diffraction, and any multiple path deviation in signal propagation[4]. The mobile channels are distinct from fixed-wired mediums, due to their unpredictable nature. Multiple factors determine the received signal characteristics like atmospheric effects, the signal transmission path between transmitter and receiver, an obstacle in the transmission path, ground terrain, etc [5].

Generally, FSO involves the atmosphere as a medium to transmit the signal. The weather condition affects signal propagation and sometimes be turbulent. Due to these multiple paths, the amplitude of the received signal and phase will fluctuate and also generate time delay. This reduction in signal strength is known as fading[6] and the channels which introduce the fading are known as fading channels. Hence, the main issue in multipath propagation is fading, and delay spread[7].The concept of multipath propagation such as scattering, diffraction, and reflection is shown in figure-1. In this paper, the effect of two random signals on the wireless network is analyzed using MATLAB.

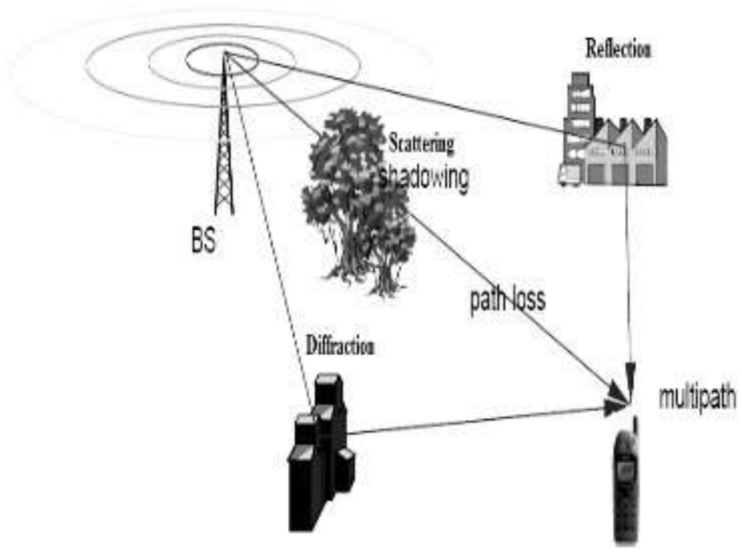

Figure 1: Multipath Propagation

To analyze the effectiveness of the signal transmission and the system performance, some important parameters such as Bit Error Rate (BER), Carrier to Noise ratio(SNR), bit energy per noise(Eb/N0), outage probability, Power margin, Doppler shift can be considered. The main contributions of the paper are the following:

1.The values of BER for Quadrature Phase Shift Keying (QPSK) is derived in terms of SNR in a Rayleigh channel and Rician channel.

2. Results for the two fading channels are analysed and compared in terms of their probability density function (PDF) , frequency response graph, BER, constellation diagram at various phase shift.

This paper is arranged as follows: The principle of fading in a wireless system is discussed in section-2, Section-3 represents the classical modelling approach, the description of the simulation setup is described in section-4, and simulation results are discussed in section-5. Section 6 is the conclusion of this work.

2. Fading in a Wireless system

In any wireless network, the signal can propagate from a transmitter to receiver in more than one path i.e., multipath transmission. The wireless environment is highly unstable; hence the signal leads to fast changes in the phase and magnitude of the signal. However, in multipath radio transmission, if sender/receiver or both are movable and signal bandwidth influence the fading[8].

As shown in figure 2, fading may be of two types: large scale and small-scale fading. Large scale fading is the signal loss comes from huge and tall areas such as hills, mountains, large building[9].In mobile communication, this large-scale fading happens in outdoor to the indoor and urban area. The short-term rapid fluctuations in signal magnitude due to small changes within the spatial distance between sender and destination refer to small-scale fading. The effect depends on various parameters such as speed of mobile stations, the speed of neighbouring objects and transmission bandwidth. It exists at a high frequency of the carrier (900 MHz or 1.9 GHz for the cellular network)[10]. To develop small scale fading, both Rayleigh and Rician fading's are proposed.

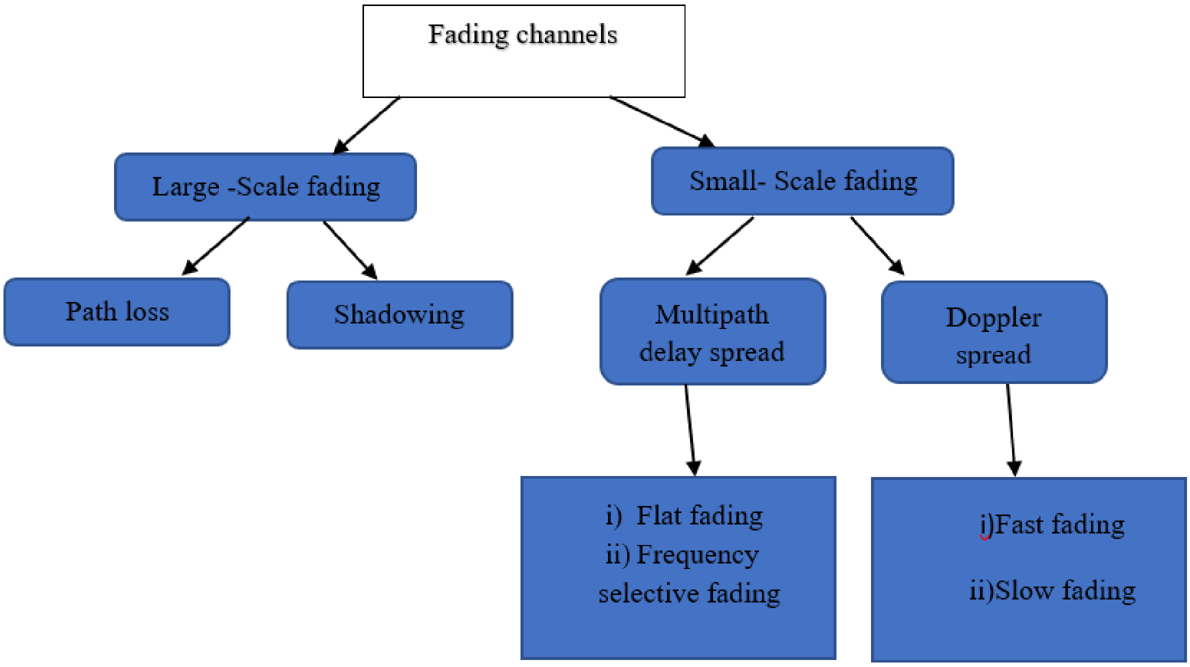

Figure 2. Classification of Fading

Clarke proposed a mathematical description for wireless propagation with complex channel gain. But it is valid only under the flat fading assumption with a particular power spectral density[11].In [12] the characteristics of three different types of fading channels have been discussed and the effect of link distance is simulated in various channel models. Effective closed-form equations for the Binary Phase Shift Keying (BPSK) BER with maximum ratio combing(MRC) diversity system in the presence of co-channel interference in Rayleigh channel fading and AWGN are derived in [13]. To evaluate the efficiency of MRC scheme, the derived equation was used. In [7] both the fading channels have been compared based on the mean value of the received signal level, RF random fluctuation, outage probability, and the impact of Doppler velocity as well as the dispersion in received signal have been discussed. In[14], a single channel optical transmission system is analyzed with the effect of noise. Here, the system has been designed using the On-Off keying (OOK) modulation method for the transmission of the light wave. But OOK has low spectral efficiency as compared to QPSK. Hence, the proposed method is implemented using the QPSK modulator. In [15] detailed comparative analysis of various types of Rayleigh fading channel simulators has been discussed. Here, the median and peak power margins, the root mean square error of PSD and the Kullback-Leibler divergence criteria have been proposed as measuring parameters to evaluate the simulator performance. In[16] the performance of Sum-of-cisoids (SOC) Rice and Rayleigh simulators have been analyzed in terms of bit error probability(BEP) of QPSK and DPSK systems. This work has been done only when transmission paths are minimum with nonuniform gain.

3. Classical Model

Generally, Clarke's method is preferred as a reference model and sometimes considered as an estimated inefficient model in comparison with Jake's Rayleigh fading simulator. In this portion, the fundamental of Rayleigh distribution is discussed and a design with N number of the transmission path is considered.

3.1 Rayleigh Fading:
The transmitted signal can be travelled in a direct path (LOS) or an indirect path (NLOS). When there is no LOS exists between the source and destination point than the signal distracts from its original path and produces various scattered wave is known as Rayleigh Fading. The resultant output is the sum of all reflected and scattered signals [17]. Mathematically, the channel impulse response is modelled in the Rayleigh channel as,

$$h(n) = \sum_{i=0}^{k} \alpha_i \delta(n - n_i) \quad (1)$$

Where k represents the number of channel paths, n_i is the path delay, δ(.) represents the delta Dirac function, and α_i is the complex value.

Rayleigh fading will occur under Rayleigh distribution, which is used to design a faded signal. It is the radial element of the summation between two uncorrelated random variables Gaussian in nature [18]. The two variables are in-phase and quadrature-phase elements, used to determine the received signal envelope.
Mathematically,

$$E = [|I(t)|^2 + |Q(t)|^2]^{\frac{1}{2}} \quad (2)$$

Where E represents the envelope of complex signal; I(t)= In-phase component; Q(t) = out of phase component.

Only for huge value of signal, these two above components behave like Gaussian. The probability function (Rayleigh Distribution) of the above-mentioned amplitude response can be written as

$$S(f) = \frac{r}{\sigma^2} exp\left(-\frac{r^2}{2\sigma^2}\right) r \geq 0 \quad (3)$$

Where S(f) is probability distribution function of received signal,$2\sigma^2$ is the average power and r represents the amplitude of the envelope. While the phase is uniformly distributed.

The random process of this fading with N multi-paths is represented in terms of complex fading envelope and is denoted by X(t).It is described as [11]

$$X(t) = E \sum_{n=1}^{N} D_n \left[j(\omega_d tCOS\alpha_n + \varphi_n)\right] \quad (4)$$

Where E implies scaling constant, N is the multiple paths, ω_d is the maximum Doppler angular frequency (in radian) and Dn , φ_n ,α_n are amplitude gain, initial phase and angle of arrival(AOA) of the n^{th} transmission path respectively.

Under the above assumption, and for a large value of multiple paths N the improved Rayleigh simulation model can be formulated as[19][20]

$$X(t) = x_I(t) + jx_Q(t) \quad (5)(a)$$

According to the central limit theorem the real part of $x_I(t)=\mathscr{R}[x(t)]$ and imaginary part of $x_Q(t) = \mathscr{I}[x(t)]$ can be equivalent to a Gaussian random process. Here,

$$\Re[x(t)] = \sqrt{\frac{2}{N}} \sum_{n=1}^{N} \cos(2\pi f_d t \cos\alpha_n + \varphi_n) \quad (5)(b)$$

$$\Im[x(t)] = \sqrt{\frac{2}{N}} \sum_{n=1}^{N} cos(2\pi f_d t \sin\alpha_n + \varphi_n) \quad (5)(c)$$

The autocorrelation function (ACF) of real part and imaginary part have written as

$$R_{XX}(\tau) = j_0(2\pi f_d t) = R_{XIXI}(\tau) + R_{XQXQ}(\tau) \quad (6)$$

To improve the correlation between the signal and to reduce the angle of arrival the parameters used in the equation (4) can be considered as

$$\hat{X}(t) = E\sum_{n=1}^{N} \widehat{D}_n exp\left[j(\omega_d tcos\widehat{\alpha_n} + \widehat{\emptyset n})\right] \quad (7)$$

3.2 Rician Fading:

It occurs when there is a direct path between the sender and reception side. Due to the variable path length, phases are random along with the instantaneous received power [21]. In Rician fading, the strong dominant factor is the LOS. This is designed by using two Gaussian random variables with Zero and with non-zero mean. Here the PDF of the Rician signal envelope follows Rician distribution [22] which can be represented as

$$S_R(f) = \frac{r}{\sigma^2} exp\left(-\frac{r^2+A^2}{2\sigma^2}\right) I\left(\frac{rA}{\sigma^2}\right) \quad (8)$$

Where I represent the modified zeroth order Bessel function, A is the maximum amplitude, σ^2 is the average power of the received signal. Rician distribution is usually interpreted as to a factor Rician coefficient s. It is defined as the ratio between the signal power from direct path to an indirect path. It is expressed as

$$s(dB) = 10log\left(\frac{A^2}{2\sigma^2}\right) \quad (9)$$

In equation (9) If A tends to zero, then K goes to ∞ dB and the direct path is eliminated. The amplitude of the envelope also decreases and envelope distribution degenerates to Rayleigh [23].

4. Mathematical Model

In the suggested model, Doppler elements such as frequency and velocity has been defined and the filter sequence is modified by including changes in its existing coefficients proposed by Dhaka [24]. The generation of a modified signal of X(t) using an altered filtering sequence is shown in figure 3.

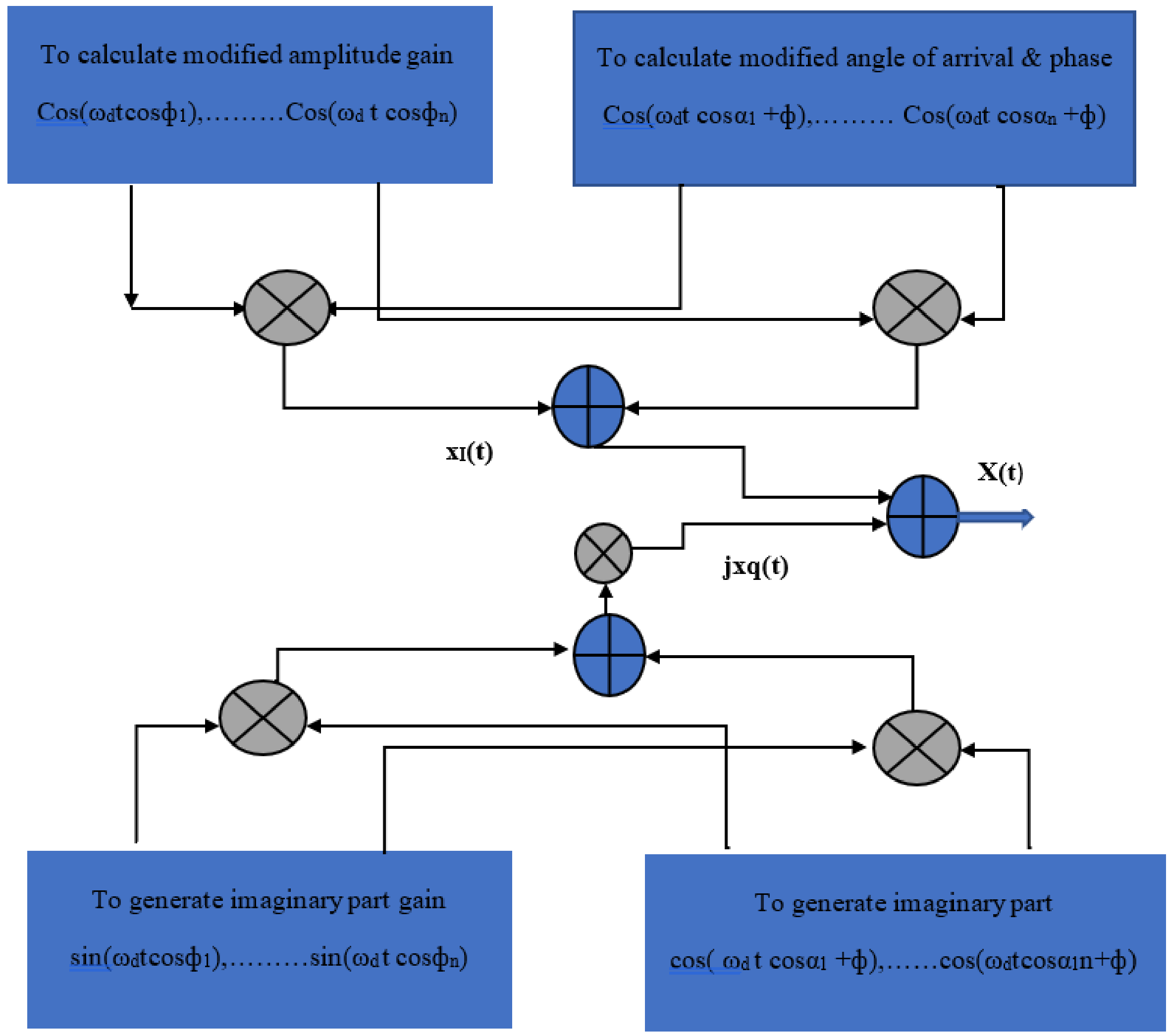

Figure 3: Proposed model for generating a modified filter sequence

As the objective of this model is to generate minimum phase shift over a particular area so the AOA is considered within the range [-π/2, π/2]. Thus, the new modified expression will be[25]

$$\alpha_n = \frac{\beta}{2}\theta_{1,n} + (1-\beta)\theta_n + \frac{\beta}{2}\theta_{2,n} \quad (10)$$

Where ϴn = uniformly distributed angle and β is the weighting factor related to individual element which can be selected between [0,0.5]. When β is nearer to zero then the value of α_n is closer to assumed limit -pi/2 to pi/2. $\Theta_{1,n}$ and $\Theta_{2,n}$ is statistically independent .By putting the above expression in equation (7), the new expression for the envelope becomes

$$\hat{X}(t) = E\sum_{n=1}^{\infty}\hat{D}_n exp\left[j\left(\omega_d tcos\left(\frac{\beta}{2}\theta_{1,n} + (1-\beta)\theta_n + \frac{\beta}{2}\theta_{2,n}\right) + \widehat{\theta_n}\right)\right] \quad (11)$$

5. Simulation results

In this portion, the performance of the proposed modified filter sequence in the Rayleigh channel is evaluated using the MATLAB tool box. The variation in autocorrelation function is observed with changing of Doppler frequencies which are plotted in figure-4 and the system is simulated at M=8 & 16.

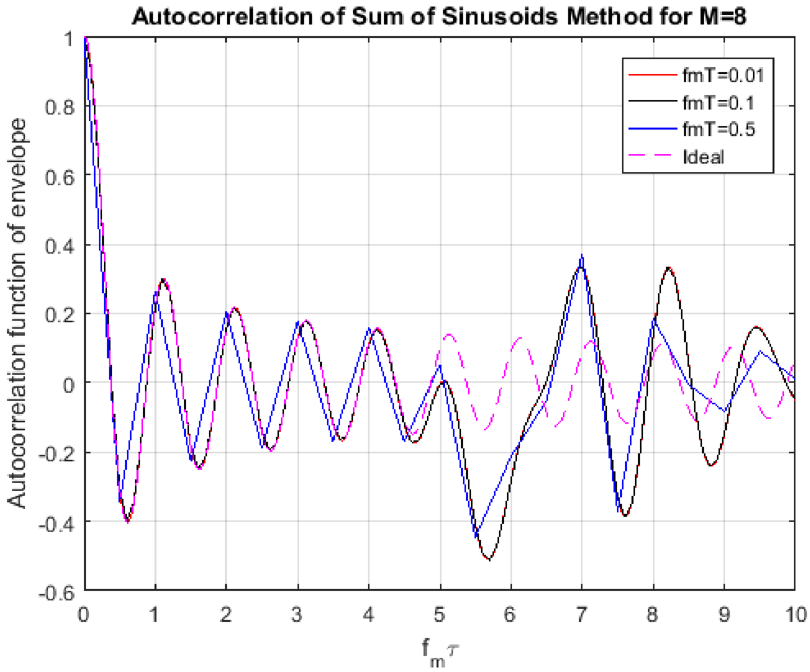

Figure 4 (a) Autocorrelation function for M=8

Normalized value of used Doppler frequencies are f_mT= 0.01,0.1 & 0.5 .From the figure, it has been found that the obtained envelope of the output sequence is similar to the output of an ideal filter in the case of M=16.

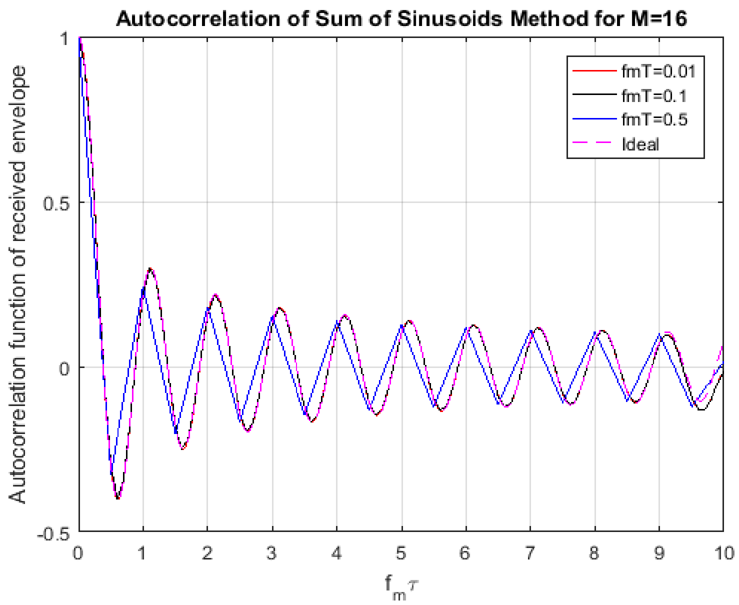

Figure 4 (b) Autocorrelation function for M=16

As compared to the theoretical shape of PDF, the simulated result is nearly the same at a smaller number of samples. And if the samples increase then the resultant output has a better choice with an ideal one. The PDF of the fading envelope of the design is compared with the ideal case for the

Rayleigh & Rician model as shown in figure 5 and figure 6. The PDF for Rayleigh distribution is simulated for variance=0.3 and for Rician distribution the coefficient has been taken as 0,1,2&4.

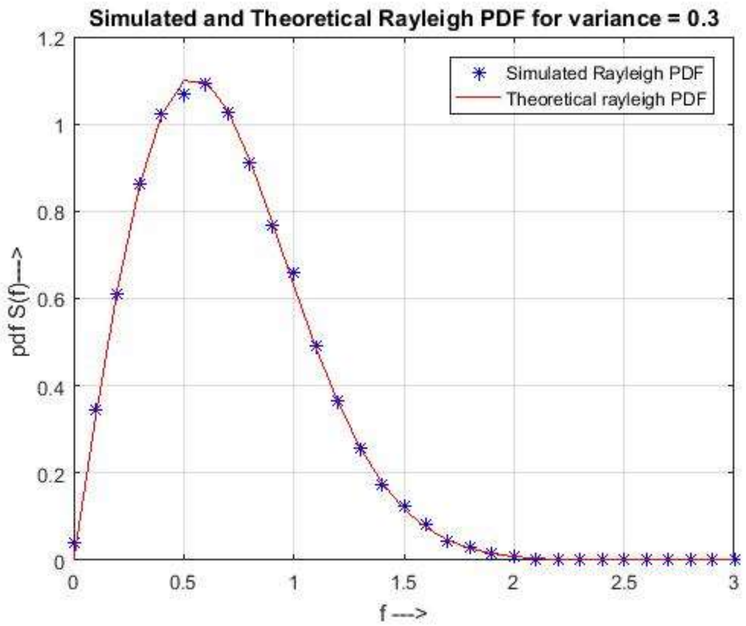

Figure 5 : Rayleigh PDF of variance 0.3

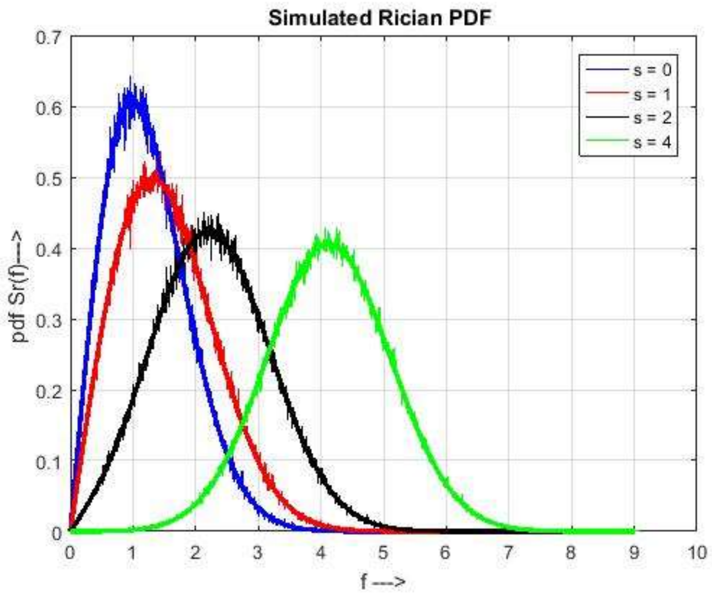

Figure 6: Rician PDF for fading envelope

For aggregate averages based on 10,00,000 random samples, results are validated. To plot the PDF of the generated method, Histogram is used and its phase plot is also drawn. Figure 7 shows the histogram of the phase component calculated from the proposed model.

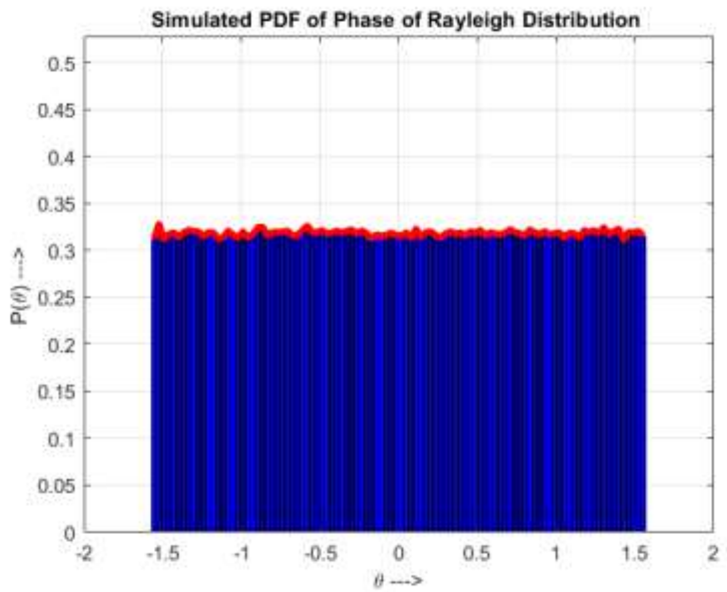

Figure 7: Histogram of Phase component for Rayleigh distribution

From the above graph, it is evaluated that the phase of random variables follows uniform distribution. The plot of Eb/No vs. BER has been drawn by varying SNR, using MATLAB coding.

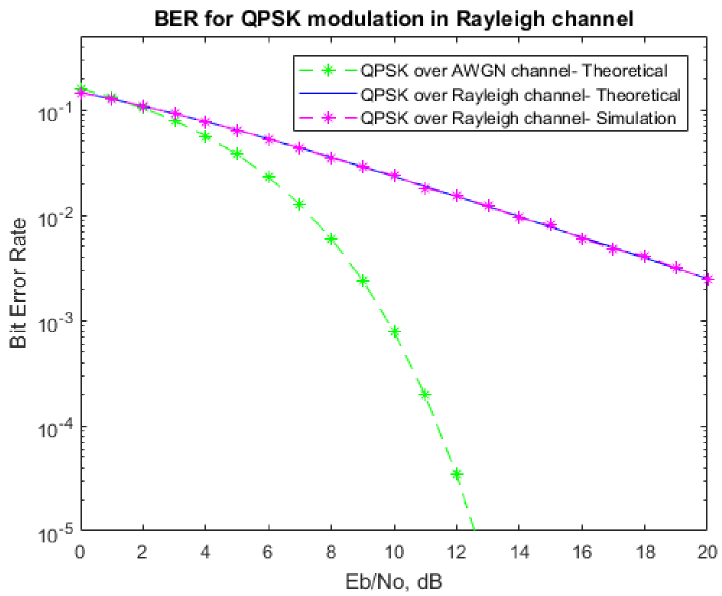

Figure 8: BER performance of the proposed model

As shown in Figure 8, the BER plot obtained in the analysis of results showed that the design works well on SNR less than 20 dB. The BER output of two fading paths as a function of bit energy per noise power with QPSK is performed using the velocity=90km/hr[26].

6. Conclusion

In this article, various statistical constraints are derived for the proposed model, such as envelope

PDF, autocorrelation, and cross-correlation, which indicate an integrative solution following the reference model. Also, a modified filtering sequence is used to obtain Doppler components and to produce the amplitude envelope. For a better efficient result, a large number of samples can be considered. A SOS method is used to compare the performance of AWGN & Rayleigh fading channel with the QPSK system. As future work, the wireless communication system must be evaluated for different real channel scenarios and for measuring the noise performance in next-generation signal transmission.

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